

Emergence and Seedling Structure of Temperate Grasses at Different Planting Depths

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ABSTRACT

Some producers have adopted ecologically based practices such as planting complex forage mixtures in their grazing systems to exploit the potential benefits of biodiversity. An understanding of grass seedling emergence and structure under different planting conditions could help develop planting recommendations for establishing multispecies swards. We conducted controlled-environment and field studies to compare the seedling emergence and morphology of several grasses at three planting depths. Perennial ryegrass (*Lolium perenne* L.; diploid and tetraploid cultivars), orchardgrass (*Dactylis glomerata* L.), prairiegrass (*Bromus catharticus* Vahl), and brome grass (*Bromus stamineus* Desv.) were planted at 1, 3, and 6 cm in the growth chamber and greenhouse. Seedlings were destructively sampled 14 d after emergence, and leaves, tillers, and roots were counted. Mesocotyl length and coleoptile width were measured. The grasses were planted in two field experiments to determine emergence and seedling size when planted at 1, 3, or 6 cm. Both perennial ryegrass and orchardgrass elongated the mesocotyl from 1 to 4 cm depending on planting depth, but brome grass and prairiegrass did not. Seedlings of brome grass and prairiegrass had greater mass but fewer tillers and roots than perennial ryegrass. Increased planting depth reduced seedling size by reducing the number and size of leaves and number of tillers by 15 to 30% in all grasses. Differences in seedling size and structure among cultivars within species were positively correlated (r of 0.8 to 0.9, $P < 0.05$) with seed mass. Variation in seed mass and coleoptile width, however, did not explain differences among grasses in seedling emergence in the field.

COOL-SEASON GRASSES predominate in the pastures and haylands of the northeastern USA (Baylor and Vough, 1985). Orchardgrass is commonly recommended for pastures in this region because of its better drought tolerance and winter hardiness compared with perennial ryegrass (Van Santen and Sleper, 1996; Christie and McElroy, 1994). Producers, however, may prefer perennial ryegrass because of its greater nutritive value and establishment ability compared with other grasses. Prairiegrass has been investigated as an alternative pasture species because of its extended growth in the fall and rapid spring growth (Hall et al., 1996; Sanderson et al., 2002). *Bromus stamineus* Desv., recently introduced as a cool-season grass for pastures, has been reported to be more tolerant of drought and hard grazing than prairiegrass (Stewart, 1992).

Recent ecological research indicates that plant species diversity in temperate grasslands may benefit ecosystem productivity through more efficient nutrient use, facilitation among plant species, and niche differentiation among other mechanisms (Tilman et al., 1999; Minns

et al., 2001; Sanderson et al., 2004). Some producers have begun to apply this new knowledge to establishing diverse mixtures of forage species (e.g., grasses, legumes, and forbs) in pastures (Sanderson et al., 2001) and have concerns about establishment methods. These producers require new knowledge of the emergence, growth, and development of forage seedlings for devising appropriate management practices and formulating potential seed mixtures for multispecies plantings.

Recommended planting depths for temperate forage grasses, such as perennial ryegrass and orchardgrass, range between 1 and 1.5 cm (Askin, 1990). Clark (1985) recommended planting 'Matua' prairiegrass no deeper than 4 cm. Planting small-seeded forages too deep in the soil reduces emergence and vigor of seedlings, which frequently leads to poor establishment (Arnott, 1969; Ries and Hoffman, 1995). Improper planting depth can result from poorly packed seedbeds, uncalibrated equipment, or the belief that seeds planted deeper in the soil may have greater chances of accessing soil moisture. Greater seed mass of cool-season grasses was associated with increased seedling emergence at 1- and 3-cm planting depths (Andrews et al., 1997). It was concluded that larger grass seedlings had an increased coleoptile and mesocotyl width, which resulted in greater shoot strength to penetrate the soil.

Previously, we developed new information on alternative forages, such as chicory (*Cichorium intybus* L.) and narrowleaf plantain (*Plantago lanceolata* L.), for use in complex pasture mixtures (Sanderson and Elwinger, 2000a, 2000b; Sanderson et al., 2003). The objective of the current study was to develop similar information for selected temperate perennial grasses. We conducted growth chamber and greenhouse experiments to examine seedling morphology of grasses when planted at several depths followed by two field experiments in different environments to examine emergence and seedling structure under field conditions.

MATERIALS AND METHODS

Greenhouse and Growth Chamber Trials

In the growth chamber, three seeds of each grass cultivar (Table 1) were planted at 1-, 3-, or 6-cm depths in 5-cm-diam. by 21-cm-deep containers filled with sand. The containers were packed to a bulk density of 1.92 g cm^{-3} with a field capacity of $0.21 \text{ m}^3 \text{ m}^{-3}$. Fifteen containers (replicates) of each cultivar-seeding depth combination were planted. Seedlings were thinned to one per container soon after emergence. Because of the number of containers, two growth chambers were used. One chamber contained seven replicates (blocks), and the other contained eight replicates of each treatment. Temperature was maintained at 25°C during the day and 15°C during the night. Daylength was 16 h, and relative humidity ranged from 50 to 70%. Light in the chambers was provided by a mixture of incandescent and fluorescent bulbs at 216

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Table 1. Description of grasses used in controlled-environment and field trials.

Species	Cultivar	Description	Seed mass
			mg
Perennial ryegrass	Aubisque	tetraploid, medium maturity	3.42
	Madera	tetraploid, late maturity	3.35
	Mongita	diploid, medium maturity	2.74
	Moranda	diploid, late maturity	2.06
Orchardgrass	Dawn	medium maturity	1.01
	Pennlate	late maturity	1.12
Prairiegrass	Matua		9.03
Bromegrass	Gala		10.29

μmol photosynthetic photon flux density (PPFD) $\text{m}^{-2} \text{s}^{-1}$ with a red/far-red ratio of 1.61. Plants were watered once daily to about field capacity with half-strength Hoagland solution.

The experiment was repeated in the greenhouse during January 1998. The same procedures were used except that containers were filled with a mixture of potting soil (Scots-Sierra Horticultural Products, Marysville, OH)¹ and Morrison (fine-loamy, mixed, mesic Ultic Hapludalfs) soil. The containers were packed to a bulk density of 1.52 g cm^{-3} with a field capacity of $0.24 \text{ m}^3 \text{ m}^{-3}$. Temperature in the greenhouse varied from 23 to 41°C during the day and 13 to 24°C at night. Relative humidity ranged from 10 (day) to 100% (night). Natural light was supplemented (but the natural daylength was not extended) with artificial light from 400-W lamps providing $260 \mu\text{mol PPFD m}^{-2} \text{s}^{-1}$ at plant height during the experiment. Red/far-red ratio of the supplemental light was 1.61 compared with 1.31 for natural-light levels. Plants were watered once daily, and no additional nutrients were added.

The date of seedling emergence was recorded for each container in both trials. At 14 d after planting, the number of leaves and tillers per plant were counted, plants were removed from the container, and the soil was washed from the roots in cold running water. Leaf area was determined with a LI-COR 3000 leaf area meter (LI-COR, Lincoln, NE). Root length was measured from the crown node to the tip of the longest root. Mesocotyl and epicotyl (first leaf internode) length were measured if elongated. The shoots and roots were separated at the coleoptilar node and dried at 55°C for 48 h to determine the dry mass. Width of the coleoptile from seedlings at the 1-cm depth was measured in the growth chamber trial. Width was measured at the base, midpoint, and top of the coleoptile and the measurements averaged.

Field Trials

Two field trials were conducted at the Russell E. Larson Agricultural Research Center near Rock Springs, PA (40°48' N, 77° 52' W; 350 m above sea level), to determine seedling emergence from three depths. Soil at the site was a Hagers-town silt loam (fine, mixed, semiactive, mesic Typic Hapludalfs). Analysis of soil samples to a 15-cm depth indicated a pH of 6.5, 122 kg ha^{-1} of available P, and 179 kg ha^{-1} of available K. No fertilizer was applied in either trial, and the plots were not irrigated.

The trials were planted on 1 July and 1 September 1998. The experimental site was cultivated and rototilled to a 15-cm depth. For the July planting, furrows that were 0.5 m long were made in the soil to the appropriate depth (1, 3, or 6 cm) with a calibrated board. Then, 100 seeds were placed into the furrow and the seed covered with soil. The site was then rolled twice (at right angles) with a water-filled drum to pack the

soil. The procedures were the same at the September planting except that row length was increased to 1 m, and only 50 seeds were planted per row. There was 0.5 m between the rows and blocks in each experiment.

The emerged seedlings in each row were counted daily or every other day for 2 wk, and then they were counted weekly for 3 wk. On 4 August (1 July planting, 35 d after planting) and 16 October (1 September planting, 45 d after planting), all seedlings in each row were excavated to a 10-cm depth and the number of live emerged seedlings counted. Five seedlings were selected at random, and the number of tillers and leaves and seedling dry mass (55°C for 48 h) were determined. The number of emerged seedlings was normalized to the number of potential seedlings based on laboratory estimates of germination percentage of each cultivar.

Data for growth chamber, greenhouse, and field trials were checked for normality and transformed as necessary. Data are presented on the original scale with footnotes indicating when significance tests were calculated on a transformed scale. The experimental design in all experiments was a 3 (planting depth) \times 8 (grass cultivar) factorial arrangement of treatments in randomized complete blocks. There were 15 blocks (replicates) in the growth chamber and greenhouse trials and four blocks in the field trials. The field experiments were analyzed separately because of missing data from the orchardgrass treatments in the September trial. Planned comparisons were used to compare treatment means. Contrasts were Matua prairiegrass + 'Gala' bromegrass vs. the perennial ryegrass cultivars; Matua + Gala vs. the orchardgrass cultivars; Matua vs. Gala; orchardgrass vs. perennial ryegrass; 'Pennlate' orchardgrass vs. 'Dawn' orchardgrass; diploid perennial ryegrass vs. tetraploid perennial ryegrass; and medium-maturity cultivars of perennial ryegrass vs. late-maturity cultivars. Statistical significance was declared at $P < 0.05$, unless otherwise indicated.

RESULTS AND DISCUSSION

Greenhouse and Growth Chamber Trials

In both trials, the main effects of planting depth and grass cultivar were significant for nearly all seedling attributes measured. There were a few instances of depth \times cultivar interactions; however, these were caused by small changes in magnitude of response (easily detected with 15 replicates) and not by changes in the direction of response. Therefore, we focus on the main effects.

Gala bromegrass and Matua prairiegrass did not elongate the mesocotyl during emergence (Table 2), similar to other results for Matua and other *Bromus* species (Andrews et al., 1997; Newman and Moser, 1988). Perennial ryegrass and orchardgrass both elongated the mesocotyl during emergence, but there was no significant difference between the two species. The diploid ryegrass cultivars had a 27% greater mesocotyl elongation than tetraploid cultivars in the growth chamber but not in the greenhouse. Mesocotyl elongation of ryegrass and orchardgrass increased 5- to 10-fold with deeper planting in both trials. Perennial ryegrass and orchardgrass elongated the epicotyl 1.1 to 1.6 cm in addition to elongation of the mesocotyl when planted at the 6-cm depth (data not shown). The mesocotyl and epicotyl accounted for about 4.5 cm of seedling elongation; thus, the coleoptile had to push through the remaining 1.5 cm of soil to emerge from the 6-cm planting depth. Coleoptile width was greatest for Matua prairiegrass and Gala

¹ Reference to a trade or company name is for specific information only and does not imply approval or recommendation of the company or product by the USDA to the exclusion of others that may be suitable.

Table 2. Least-squares means of mesocotyl length and coleoptile width of grass seedlings in the growth chamber (GC) and greenhouse (GH) trials.

Species	Cultivar	Mesocotyl length		Coleoptile width
		GC	GH	GH
		cm		mm
Perennial ryegrass	Aubisque	1.86	0.423 (1.91) [†]	0.76
	Madera	1.68	0.412 (1.85)	0.67
	Mongita	2.14	0.393 (1.75)	0.71
	Moranda	2.35	0.432 (1.98)	0.69
Orchardgrass	Dawn	1.85	0.360 (1.32)	0.56
	Pennlate	2.13	0.452 (1.22)	0.56
Prairiegrass	Matua	0	0	0.82
Bromegrass	Gala	0	0	0.88
SE		0.102	0.0197	0.043
Contrasts				
Matua + Gala vs. orchardgrass		NA [‡]	NA	**
Matua + Gala vs. ryegrass		NA	NA	**
Orchardgrass vs. ryegrass		NS [§]	NS	**
Gala vs. Matua		NA	NA	NS
Dawn vs. Pennlate		NS	NS	NS
Diploid vs. tetraploid		**	NS	NS
Medium vs. late		NS	NS	NS
Planting depth				
1 cm		0.40	0.190 (0.46)	
3 cm		1.60	0.443 (1.36)	
6 cm		4.00	0.602 (2.37)	
SE		0.074	0.0144	
Significance		**	**	

** Significant at the 0.01 probability level.

[†] Data were $\log_{10} + 1$ transformed for analysis. Probability levels for contrasts are based on transformed data. Means are shown on the original scale in parentheses. Standard errors apply to the transformed means.[‡] NA, not applicable.[§] NS, not significant.

bromegrass, followed by perennial ryegrass and orchardgrass.

Hoshikawa (1969) classified the seedling morphology of grass species and described six types of underground seminal structures based on the presence or absence of mesocotyl elongation, nodal roots, and mesocotylar roots. *Bromus* and *Lolium* species were classified by Hoshikawa (1969) as Type B Festucoid seedlings, which elongate the mesocotyl but have no mesocotylar roots. *Dactylis* sp. was classified as a Type D Festucoid seedling, which elongates the mesocotyl but has no transitional nodal or mesocotylar roots. We did not observe mesocotylar roots on seedlings of any species. In our study, however, Gala bromegrass and Matua prairiegrass (both *Bromus* species) did not elongate the mesocotyl and appeared to be more like Type A seedlings (those that do not elongate the mesocotyl) rather than Type B seedlings as described by Hoshikawa (1969).

Seedlings of Gala bromegrass and Matua prairiegrass had larger leaves but fewer tillers than perennial ryegrass in both the growth chamber and the greenhouse trials (Table 3). Orchardgrass had the smallest seedlings among the grasses studied, and there was no difference between cultivars. Seedlings of tetraploid ryegrass cultivars generally were larger in leaf area and leaf mass than diploid cultivars, and medium-maturity cultivars often were larger than late-maturity cultivars. Increased planting depth reduced seedling size by reducing the number and size of leaves along with tiller numbers by 15 to 30%. Deeper planting may have inhibited the coleoptile tiller of the grass seedlings, thereby reducing tiller number (Raju and Steeves, 1998).

Bromegrass seedlings had fewer roots but greater root mass and length than perennial ryegrass and orchardgrass (Table 4). Orchardgrass seedlings had fewer roots and less root mass and length than perennial ryegrass. Within the ryegrasses, the medium-maturity cultivars (Aubisque and Mongita) had more and heavier roots than the late-maturity cultivars (Madera and Moranda). The tetraploid ryegrass cultivars had greater root mass than diploid cultivars. Orchardgrass cultivars did not differ in root attributes.

Planting depth had fewer significant effects on root than shoot attributes. Root mass for all grasses was the least at the 6-cm planting depth, whereas root number was not affected by planting depth (Table 4). Root length decreased with increased planting depth in the growth chamber. In the greenhouse, however, root length did not change with planting depth.

Most of the differences in seedling attributes among orchardgrass and perennial ryegrass cultivars in the controlled environments could be explained by differences in seed mass. When Gala bromegrass and Matua prairiegrass were excluded from the analysis, nearly all seedling attributes were positively correlated with seed mass (Table 5). The relationship between seed mass and seedling size has been noted for several other grasses as well (Naylor, 1980; Fulbright et al., 1985; Kilcher and Lawrence, 1970).

Field Trials

There was no depth \times cultivar interaction for seedling attributes in the July trial. Because the orchardgrass cultivars did not emerge from the 6-cm planting depth

Table 3. Least-squares means of grass seedling shoot attributes in the growth chamber (GC) and greenhouse (GH) trials.

Species	Cultivar	Leaves		Leaf area		Leaf mass		Tillers	
		GC	GH	GC	GH	GC	GH	GC	GH
		no.		cm ²		mg		no.	
Perennial ryegrass	Aubisque	4.3	3.6	3.16 (10.1) [†]	1.38 (2.8)	41.6	2.22 (11.6)	2.0	1.6
	Madera	4.1	3.4	2.78 (8.1)	1.26 (2.2)	32.6	2.04 (9.2)	1.9	1.4
	Mongita	4.3	3.7	2.84 (8.5)	1.27 (2.3)	27.7	2.00 (8.7)	2.0	1.5
	Moranda	4.1	3.5	2.62 (7.5)	1.08 (1.5)	21.3	1.76 (6.0)	1.9	1.3
Orchardgrass	Dawn	3.6	3.2	2.42 (6.3)	1.03 (1.3)	18.1	1.60 (4.6)	1.6	1.1
	Pennlate	3.2	3.3	2.39 (6.2)	1.06 (1.4)	15.4	1.54 (4.1)	1.5	1.2
Prairiegrass	Matua	3.9	2.8	4.20 (18.1)	1.57 (4.3)	64.4	2.26 (12.4)	1.2	1.0
Bromegrass	Gala	4.1	3.1	3.78 (14.8)	1.49 (3.5)	52.7	2.25 (11.8)	1.5	1.1
SE		0.18	0.13	0.131	0.041	3.43	0.049	0.09	0.08
Contrasts									
Matua + Gala vs. orchardgrass		**	NS [‡]	**	**	**	**	*	NS
Matua + Gala vs. ryegrass		NS	**	**	**	**	**	**	**
Orchardgrass vs. ryegrass		**	**	**	**	**	**	**	**
Gala vs. Matua		NS	*	**	*	**	NS	**	NS
Dawn vs. Pennlate		NS	NS	NS	NS	NS	NS	NS	NS
Diploid vs. tetraploid		NS	NS	**	**	**	**	NS	NS
Medium vs. late		NS	*	**	**	**	**	NS	**
Planting depth									
1 cm		4.3	3.8	3.16 (10.8)	1.4 (3.5)	36.5	2.20 (11.6)	1.8	1.6
3 cm		4.0	3.3	3.15 (10.6)	1.3 (2.4)	37.7	1.96 (8.3)	1.8	1.2
6 cm		3.6	2.8	2.76 (8.5)	1.1 (1.4)	28.4	1.72 (5.7)	1.5	1.1
SE		0.13	0.09	0.113	0.030	2.98	0.034	0.06	0.06
Significance		**	**	**	**	**	**	**	**

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

[†] Data for leaf area in the growth chamber were square root transformed, and data for leaf area and leaf mass for the greenhouse were cube root transformed for analysis. Probability levels for contrasts were based on transformed data. Means are shown on the original scale in parentheses. Standard errors apply to the transformed means.[‡] NS, not significant.

in September, we present the simple effects means for seedling attribute data for that trial.

Emergence of all species and cultivars was reduced as planting depth increased in both July and September field experiments (Table 6). Emergence of grasses from the 3- and 6-cm depths was much less in September than July. Dawn and Pennlate orchardgrass did not

emerge from the 6-cm depth in September but averaged 10% emergence from the 6-cm planting depth in July. Emergence of all grasses was drastically reduced at the 6-cm planting depth. Ploidy level of the perennial ryegrass cultivars did not affect seedling emergence in the field. Improved seedling emergence was reported for tetraploid cultivars compared with diploid cultivars in

Table 4. Least-squares means of grass seedling root attributes in the growth chamber (GC) and greenhouse (GH) trials.

Species	Cultivar	Roots		Root mass		Root length	
		GC	GH	GC	GH	GC	GH
		no.		mg		cm	
Perennial ryegrass	Aubisque	10.6	9.7	16.3	21.0	13.8	10.5
	Madera	9.4	8.6	12.9	16.3	13.5	11.9
	Mongita	10.0	9.7	13.8	13.4	13.5	8.7
	Moranda	9.0	8.7	10.2	11.4	12.9	9.2
Orchardgrass	Dawn	7.6	7.5	7.5	11.1	11.5	12.7
	Pennlate	7.5	7.3	5.3	6.5	10.5	9.6
Prairiegrass	Matua	6.8	5.4	20.4	18.2	15.9	14.9
Bromegrass	Gala	7.4	5.2	23.7	19.7	16.1	14.5
SE		0.38	0.38	1.63	1.80	0.59	0.78
Contrasts							
Matua + Gala vs. orchardgrass		NS [†]	**	**	**	**	**
Matua + Gala vs. ryegrass		**	**	**	**	**	**
Orchardgrass vs. ryegrass		**	**	**	**	**	NS
Gala vs. Matua		NS	NS	*	NS	NS	NS
Dawn vs. Pennlate		NS	NS	NS	NS	NS	NS
Diploid vs. tetraploid		NS	NS	**	**	NS	**
Medium vs. late		**	**	**	**	NS	NS
Planting depth							
1 cm		8.5	7.7	15.3	14.9	14.1	10.7
3 cm		8.7	7.7	14.8	16.2	13.7	11.7
6 cm		8.4	7.9	11.2	13.0	12.5	12.0
SE		0.30	0.24	1.42	1.19	0.46	0.51
Significance		NS	NS	**	NS	**	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

[†] NS, not significant.

Table 5. Pearson correlation coefficients (r) between seed mass and seedling attributes in the growth chamber and greenhouse.

	All species in data set		Matua and Gala deleted from data set	
	Growth chamber	Greenhouse	Growth chamber	Greenhouse
Leaf area	0.94**	0.91**	0.90*	0.91*
Leaf number	0.33	-0.64	0.87*	0.70
Tiller number	-0.54	-0.44	0.88*	0.90*
Seedling mass	0.92**	0.81*	0.93**	0.95**
Root number	-0.42	-0.73	0.92**	0.83**
Root mass	0.93**	0.70	0.93**	0.87**
Root length	0.93**	0.78*	0.93**	-0.08
Coleoptile width		0.89*		0.88*

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski], which was due to a 70% greater seed mass in the tetraploid cultivars (Berdahl and Ries, 1997). Seed mass of tetraploid perennial ryegrass cultivars in our study was 41% greater than the diploid cultivars.

The period of most rapid increase in seedling emergence in the July planting occurred at 5 to 8 d after planting (data not shown). In July, a total of 4.7 cm of rain fell within 7 d after planting, and this early rainfall probably maintained soil moisture at greater depths for several days. Dry conditions before the 1 September planting (5 cm of rain fell on 10 August and 1 cm on 14 August, and no rain fell from 14 August to 2 September; Fig. 1) and relatively low rainfall during the fall trial resulted in much drier soil (Fig. 2) and probably reduced overall emergence compared with the July planting. The light rains that occurred during the September trial probably wetted only the surface few centimeters and did not benefit the seeds planted at 6 cm.

Cultivar and planting depth affected seedling struc-

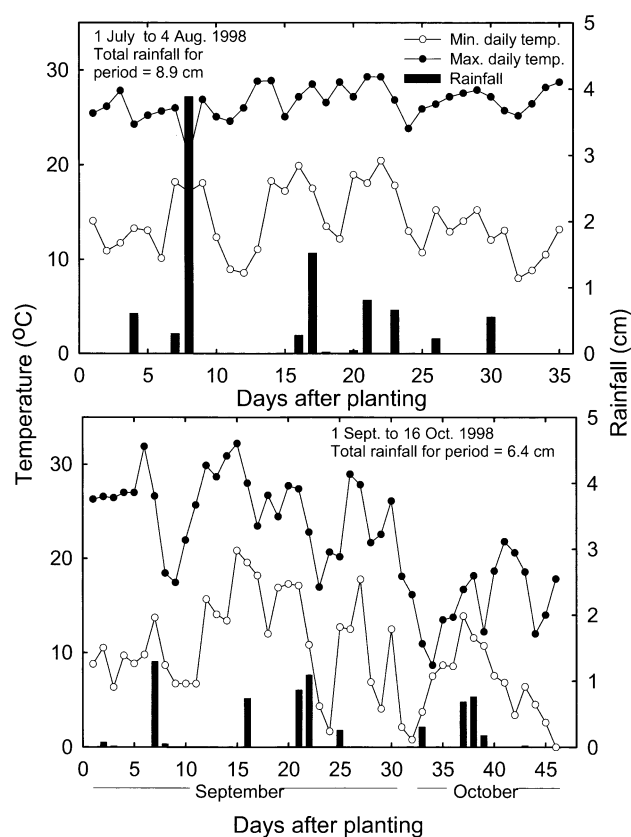
Table 6. Least-squares means of grass seedling emergence in the July and September field plantings.

Species	Cultivar	Emergence	
		July	Sept.
		%	
Perennial ryegrass	Aubisque	76	47
	Madera	64	39
	Mongita	71	47
	Moranda	59	29
Orchardgrass	Dawn	73	34
	Pennlate	50	36
Prairiegrass	Matua	42	35
Bromegrass	Gala	55	49
SE		4.8	3.3
Contrasts			
Matua + Gala vs. orchardgrass		**	*
Matua + Gala vs. ryegrass		**	NS†
Orchardgrass vs. ryegrass		NS	NS
Gala vs. Matua		NS	**
Dawn vs. Pennlate		**	NS
Diploid vs. tetraploid		NS	NS
Medium vs. late		*	NS
Planting depth			
1 cm		76	80
3 cm		66	34
6 cm		42	5
SE		3.0	2.2
Significance		*	**

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

† NS, not significant.

**Fig. 1. Rainfall and air temperatures at Rock Springs, PA, during the July and September field trials.**

ture in July and September (Table 7). Similar to controlled-environment results, Matua and Gala bromegrass had the largest seedlings in the July planting, followed by ryegrass and orchardgrass. Orchardgrass seedlings were also the smallest at all planting depths in September. Matua and Gala did not differ from the ryegrass cultivars in seedling mass in September even though the ryegrass cultivars maintained about one more leaf and tiller per seedling. Variability (i.e., the SE) in seedling mass was twice as great in September than July, perhaps reflecting the low, erratic rainfall and dry soil in September.

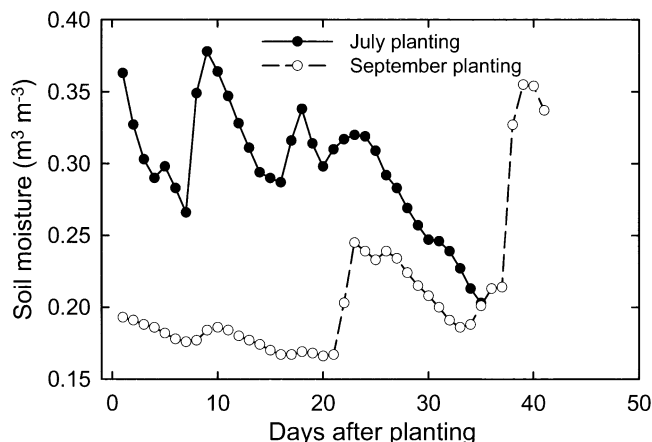
**Fig. 2. Soil moisture content at 12-cm soil depth of a grass sod near the field experimental site.**

Table 7. Least-squares means of grass seedling attributes at 35 and 45 d after planting in the July and September field plantings, respectively.

Species	Cultivar	July planting			September planting								
		Seedling mass	Leaves	Tillers	Seedling mass			Leaves			Tillers		
					1	3	6	1	3	6	1	3	6
Perennial ryegrass	Aubisque	54	3.7	2.3	30.0	56.8	50.4	3.3	3.6	3.4	2.1	2.6	2.3
	Madera	37	3.6	1.8	19.7	38.8	29.1	3.7	3.6	3.1	1.6	1.8	1.8
	Mongita	49	3.8	2.6	31.7	18.7	38.0	3.5	3.9	3.4	1.6	1.8	1.9
	Moranda	23	3.6	1.9	29.4	63.3	24.4	3.4	3.4	3.2	1.6	1.6	1.7
Orchardgrass	Dawn	14	3.0	1.2	5.2	4.5		3.0	2.8		1.0	1.1	
	Pennlate	13	3.2	1.2	3.6	8.2		3.0	2.3		1.0	1.0	
	Matua	75	3.8	1.2	27.3	27.0	27.8	3.1	2.9	3.1	1.0	1.0	1.0
Prairiegrass													
Bromegrass	Gala	59	3.6	1.3	24.2	40.7	23.6	3.0	3.3	3.5	1.0	1.1	1.0
SE		6.6	0.13	0.16	11.7	12.1	13.5	0.18	0.19	0.21	0.21	0.22	0.25
Contrasts													
Matua + Gala vs. orchardgrass		**	**	NS†	NS	*		NS	**		NS	NS	
Matua + Gala vs. ryegrass		**	NS	**	NS	NS	NS	*	**	NS	**	**	**
Orchardgrass vs. ryegrass		**	**	**	*	**		**	**		**	**	
Gala vs. Matua		NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS
Dawn vs. Pennlate		NS	NS	NS	NS	NS		NS	NS		NS	NS	
Diploid vs. tetraploid		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
Medium vs. late		**	NS	**	NS	NS	NS	NS	NS	NS	NS	*	NS

* Significant at the 0.05 probability level.

** Significant at the 0.01 probability level.

† NS, not significant.

Within perennial ryegrass and orchardgrass cultivars, seedling size and structure were positively correlated with seed mass in both field plantings ($r = 0.8$ to 0.9 , $P < 0.05$), similar to results in the controlled-environment trials. Seed mass, however, did not explain differences in emergence. Dawn orchardgrass had emergence similar to the ryegrass cultivars in July even though seed mass of orchardgrass was half that of ryegrass. Gala bromegrass and Matua prairiegrass, which had the greatest seed mass, had relatively low emergence compared with the ryegrass cultivars in July. Despite having the greatest seed mass and coleoptile width, Gala bromegrass and Matua prairiegrass did not have greater emergence than other grasses in the field. Coleoptile width was not correlated with seedling emergence (July planting, $r = -0.25$, $P = 0.54$; September planting, $r = 0.54$, $P = 0.17$).

Our results differ from Andrews et al. (1997), who reported that Matua prairiegrass had greater emergence than perennial ryegrass and orchardgrass at 1-, 3-, or 6-cm planting depths. They also reported that the effect of reduced emergence with increased planting depth was greatest on orchardgrass (a species \times planting depth interaction), the smallest-seeded grass tested. They ascribed the main causes of differences in emergence to differences in seed mass and coleoptile width. We did not observe a species or cultivar \times planting depth interaction for seedling emergence or seedling structure in the field. In our field trials, emergence of Gala and Matua was equal to or less than that of perennial ryegrass and orchardgrass even though seed mass and coleoptile width of Gala and Matua were much greater. Andrews et al. (1997) conducted their experiments on silt and sandy loam soils in New Zealand and England and irrigated the plots before and after planting. We did not irrigate our plots and subjected the seeds and seedlings to ambient rainfall and soil moisture levels along with potential soil moisture stress. The relationships

between seed mass and coleoptile width observed by others may not be applicable to nonirrigated seedbeds.

CONCLUSIONS

Grass seedling size and emergence decreased with planting depth, and responses were similar among orchardgrass, perennial ryegrass, Gala bromegrass, and Matua prairiegrass. Coleoptile width was not associated with seedling emergence in this study. Gala and Matua appeared more like Type A seedlings (those that do not elongate the mesocotyl) in terms of seedling morphology rather than Type B seedlings (those with mesocotyl elongation) as reported by others. Although perennial ryegrass, Matua, and Gala had similar emergence to orchardgrass at different planting depths, their larger seedling size compared with orchardgrass may competitively displace orchardgrass seedlings in mixed plantings.

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